Chapter 25

Impact of Replacing Conventional Cars with Electric Vehicles on UK Electricity Grid and Carbon Emissions

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Abstract This paper estimated the effect of electric vehicle transition on UK road and how it impacts on electricity supply and the reduction of carbon emissions. It used a scenario in which all cars that utilise internal combustion engines will be replaced by EVs in the UK. The methodology is based on speculating the future number of EVs in Great Britain, which helped in estimating the amount of additional electricity usage that would be required for the scenario. The results revealed that approximately 81 TWh of additional electricity must be produced annually to compensate for such expansion of EV. With that increase in electricity generation, the levels of carbon emissions from the electrical grid will rise slightly, by about 8.6 million tonnes of carbon dioxide per year. Given that combustion vehicles contribute to about 42% of the carbon emissions from the transport sector in the UK, it is concluded that the total amount of CO₂ in the country will decrease by approximately 12% of all cars with internal combustion engines are replaced by electric vehicles.

Keywords Electric · Car · Environment · Carbon · Emission

25.1 Introduction

Over the past few decades, the technology around transportation has evolved and shown dramatic developments. With the UK government pushing to go carbon neutral by 2050 [1], the demand for Electric Vehicle (EV) has had a huge rise more recently. This may due to the tendency of government legislation beginning to restrict the use of combustion vehicles (CV) on the road in order to further reduce Carbon Emission (CO₂). However, electricity is an energy source for EV which also produces CO₂ but much less than burning combustion engines. Hence, it is crucial to estimate the CO₂ reduction resulting from increasing the transition to EV. This study, therefore, analysed the reduction of CO₂ levels by comparing the current electricity usage in the UK against the scenario of UK road making 100% EV transition.

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25.1.1 Description of CV and EV

The first modern petrol internal combustion engine (ICE) was constructed in the 1880s [2]. The difference between electric and ICE vehicle is that conventional cars burn fuel in the ICE, whereas EV store energy into a battery, which powers an electric motor [3]. However, assembling the combustion vehicle (CV) was a complex process. Therefore, at the end of the 19th century, EV was more favoured by people, for example, 90% of taxicabs were electric in 1899's New York [4].

In CV, the mixture of fuel and air is ignited by the sparks, causing a small explosion, resulting in downward movements of the engine's pistons. One of the by-products of the burnt fuel is carbon dioxide, which is released in the atmosphere during this process. It has been estimated that on average, a CV emits about 122 carbon dioxide per kilometre [5]. For EV, the electric energy is stored in the battery of the car and it provides power to the car's controller. The controller transfers that energy to the electric motor, which generates horsepower to spin the wheel [3]. Some models have a motor that is installed on each axle [6]. In research studying the performance of both CV and EV, it was found that EVs are 3.6 times more efficient in energy consumption [7]. EV use 3.4 times less total energy while driven compared to ICE vehicles, and also that combustion-powered cars emit 4.5 times more carbon emissions while in use [7].

25.1.2 EV Market Size

According to the latest reports of the UK's Department for Transport, there were a total of 38.9 million vehicles in the country, of which 82.43% (32 million) were cars and taxis [8]. Currently, in the UK there are more than 298,000 electric car models on the roads. Recent figures show that plug-in battery vehicles make up about 34% of the total new vehicle registrations in Great Britain [9]. When it comes to emissions popularity and energy/fuel consumption, the popularity of vehicles plays an important role.

Table 25.1 summarises the popularity of EV in the UK and their energy consumption. Tesla Model 3 and Nissan Leaf are the most popular electric vehicles in the country. Annually, all cars are traveling about 415 billion kilometres, or approximately 12,968.75 km on average [8].

25.1.3 Electricity Demand and Carbon Emissions in the UK

For the last 6 years, the electricity consumption rate in the UK has been dropping, particularly for households due to milder winters in recent years [10]. According to UK government data, households consume approximately 105 TWh of electricity

Table 25.1 Most popular EV in the UK [8]

Brand and model	Registered units in 2019	Popularity (%)	Energy consumption (kWh/100km)
Tesla Model 3	5,500	20.37	25
Nissan Leaf	4,500	16.67	16
Jaguar I-Pace	3,500	12.96	22.7
BMW i3	3,400	12.59	18.6
Volkswagen e-Golf	2,900	10.74	16
Renault Zoe	2,900	10.74	16
Nissan E-NV200	1,500	5.56	20.5
Tesla Model S	1,400	5.19	16.3
Tesla Model X	1,400	5.19	24

Fig. 25.1 Electricity generation mix in the UK [12]

per year, which is reduced from 115 TWh since 2012 [10]. In energy supply, it was measured that the annual electricity production was 307 TWh in 2019, which is reduced from 325.17 TWh in 2012 [11]. In recent years, the UK's energy generation mix has reduced the use of coal and increased the usage of more renewable resources (Fig. 25.1).

Coal and gas contribute to a high amount of CO₂ in the UK. However, CO₂ level has been reducing for the last 5 years due to the reduction of using these energy sources and by increasing the use of renewable sources and nuclear power. The transport sector in Great Britain contributes to about 33% of the carbon dioxide emissions (119.6 MtCO₂) in 2019, 11% of reduction compared to 134.3 MtCO₂ in 2005 [14]. Power stations emit approximately 15% (57.4 MtCO₂/year) of the total carbon emissions [14]. It has been estimated that EV produces about 48 g of carbon emissions during the manufacturing stage, compared to 31 g for CV, but in the longer-term, CV produce significantly more emissions from burning fuels [7].

25.2 Methodology

Through the literature review, the current study acquired the required parameters to estimate the amount of electricity needed in supply and how much of CO₂ reduction can be generated for the scenario of electrifying all cars on UK road. In order to retrieve the proposed estimation, following 4 equations were set:

The study began by determining the **average energy consumption (AEC)** of EVs according to their brand and model popularity via using Eq. (25.1).

$$\sum_{i=1}^n = (EC_i \times PP_i) = AEC \quad (25.1)$$

EC represents the **electricity consumption** of each vehicle brand and model (kWh/100 km) and **PP** is the **percentage proportion** of electric cars according to their popularity, it is represented as (value)/100; **n** is the **number** of electric car brands and models included in our study that is 9 (Table 25.1).

The next stage was to calculate the total electricity needed based on the EV transition scenario, using Eq. 25.2:

$$ER = (ATD \div 100) \times AEC \quad (25.2)$$

ER represents the **energy required** based on the EV transition scenario in kWh, later converted to TWh; **ATD** is the **annual traveling distance** for all cars in the UK (km); **AEC** is the **average energy consumption** of EV (kWh/100 km). The calculation also considered that there are about 7% (**ER** + 7%) distribution losses through the electricity grid in the UK [15] (Table 25.2).

In measuring the carbon emission, the current study estimated the emissions from cars using the following Eq. 25.3:

$$Em = ATD \times CI \quad (25.3)$$

where: **Em** is the **carbon emissions** released by all cars in the UK (kg), later converted to million tonnes; **ATD** is the **average traveling distance** (km); **CI** is the **carbon intensity** of the cars (kgCO₂/km).

Since EV does not produce any emissions while driven, the value for **Em**, which represents the amount of Carbon dioxide that all cars in the UK emit annually, was subtracted from current CO₂ emission on the road today. Both current and newly estimated road CO₂ levels were compared. The final step was to estimate the changes

Table 25.2 Carbon intensity of electricity's sources [13]

Source	gCO ₂ /kWh
Coal CCS	220
Oil	314
Gas CCS	200
Nuclear	26
Hydro	7
Wind	15
Solar PV	88
Bioenergy	165
Geothermal	15

of CO₂ under the EV transition scenario. The **ER** value from Eq. 25.2 was distributed accordingly to the UK's energy generation mix (i.e. 40% for gas, 19% for nuclear, etc.) This is due to each source of electricity emits a different amount of carbon emissions per kWh of electricity produced. Equation 25.4 was used to calculate the increased CO₂ from each source and then they were summed to find the total amount.:

$$CO_2 = ES \times CI \quad (25.4)$$

CO₂ is **carbon dioxide emissions** (kgCO₂), later converted to MtCO₂; **ES** is the **electricity generated by each source** (kWh); **CI** is the **carbon intensity** of each corresponding source (kgCO₂/kWh). The total difference in annual carbon emissions based on the scenario was measured.

25.3 Results and Discussion

Using Eq. 25.1 it was calculated that the average energy consumption (AEC) by EV according to their brand and model popularity is 19.45 kWh/100 km.

Using the Eq. 25.2, it was estimated that the energy required for the EV scenario (ER) per annum would be 86.3 TWh which added the 7% grid losses, leading to a total of 22% rise in energy production at the supply phase.

In relation to carbon emissions (Eq. 25.3), the result revealed 49.5 MtCO₂/year (Em) are emitted by all CV today. EV does not produce any traffic emissions, which will lead to a 41.4% reduction in transport CO₂ levels per year.

Using Eq. 25.4, we estimated that a total of 8.6 MtCO₂/year will need to be generated additionally from the electricity grid for a 100% transition to EV.

When we compared the current annual total emissions of all sectors using the EV scenario, it was revealed that carbon emissions will drop by about 41 MtCO₂ or by 11.6% annually.

25.4 Discussion

In this research, it did not cover the detailed life cycle assessment of CV and EV, as the focus of our study was the electricity consumption based on EV transition scenario and their effect on carbon emissions in the UK. The manufacturing of EV produces slightly higher amounts of carbon emissions than the CV. On the other hand, petrol/diesel cars require fuel, which first must be extracted, processed, and transported to gas stations, all of which generated additional carbon emissions. This is subject to change, as there are constant innovations, which would lead to a reduction in carbon emissions in manufacturing processes. Besides, lots of other variations

would still need to be further explored such as energy use behaviour. For example, CV uses the engine's heat to warm up the interior space, while electric cars required electricity from the battery in order to provide thermal energy for the interior. These variables and associated future technology will have a significant impact on curbing the carbon emission within the transportation sector.

25.5 Conclusions

The expansion of electric cars in the UK would lead to an increase in electricity demand, which would result a rise in carbon emissions due to supply and manufacturing. On the other hand, transport emissions would drop significantly resulting in a total reduction of CO₂ levels by 12% per year. IT can be concluded that transition towards EV would gain a positive effect in reducing Co2 in the longer-term and further reduction can be achieved if energy efficiency increases at supply and manufacturing level.

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